



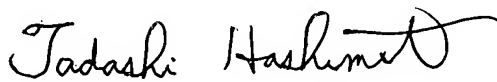
DECLARATION

I, Tadashi HASHIMOTO , a national of Japan,
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do hereby solemnly and sincerely declare:-

- 1) THAT I am well acquainted with the Japanese language
and English language, and
- 2) THAT the attached is a full, true, accurate and
faithful translation into the English language made
by me of Japanese Patent Application No. 11-006108.

The undersigned declares further that all
statements made herein of his own knowledge are true and
that all statements made on information and belief are
believed to be true; and further that these statements
were made with the knowledge that willful false statements
and the like so made are punishable by fine or imprisonment,
or both, under section 1001, of Title 18 of the United
States Code and that such willful false statements may
jeopardize the validity of the application or any patent
issuing thereon.

Signed this 2nd day of June , 2005 .



Tadashi HASHIMOTO

11-006108

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[Title of the Invention] SEMICONDUCTOR DEVICE

[Claims]

[Claim 1] A semiconductor device having a
5 multilayer structure comprising an insulating film
including silicon (Si) formed on a principle plane side
of a semiconductor substrate, a first conductive film
formed in contact with said insulating film, and a
second conductive film formed in contact with said first
10 conductive film, wherein said second conductive film has
copper (Cu) as a main constituent element, said first
conductive film has as a main constituent element one
kind of element selected from the group consisting of at
least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium
15 (Os), and platinum (Pt), and said first conductive film
contains as an added element one kind of element
selected from the group consisting of at least palladium
(Pd), cobalt (Co), nickel (Ni), and titanium (Ti).

[Claim 2] A semiconductor device having a
20 multilayer structure comprising an insulating film
including silicon (Si) formed on a principle plane side
of a semiconductor substrate, a first conductive film
formed in contact with said insulating film, and a
second conductive film formed in contact with said first
25 conductive film, wherein said second conductive film has
copper (Cu) as a main constituent element, said first

conductive film has as a main constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and said first conductive film
5 contains as an added element one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 10 at.% and not more than 25 at.%.
10

[Claim 3] A semiconductor device having a multilayer structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a copper (Cu) film or a copper (Cu) alloy film formed in contact with said first conductive film,
15 wherein said first conductive film has as a main constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and said first conductive film contains as an added element
20 one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more than 25 at.%.
25

[Claim 4] A semiconductor device having a multilayer structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a copper (Cu) film or a copper (Cu) alloy film formed in contact with said first conductive film,

wherein said first conductive film has as a main constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and
5 said first conductive film contains palladium (Pd) with a concentration of not less than 0.14 at.% and not more than 25 at.%.

[Claim 5] A semiconductor device having a multilayer structure comprising an first conductive film
10 formed on a principle plane side of a semiconductor substrate, and a copper (Cu) film or a copper (Cu) alloy film formed in contact with said first conductive film, wherein said first conductive film has as a main constituent material at least one kind of element
15 selected from the group consisting of rhodium oxide, ruthenium oxide, iridium oxide, and osmium oxide, and said first conductive film contains as an added element one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni),
20 and titanium (Ti) with a concentration of not less than 0.14 at.% and not more than 25 at.%.

[Claim 6] A semiconductor device having a multilayer structure comprising an first conductive film formed on a principle plane side of a semiconductor
25 substrate, and a gold (Au) film or a gold (Au) alloy film formed in contact with said first conductive film, wherein said first conductive film has as a main constituent element one kind of element selected from

the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and said first conductive film contains as an added element one kind of element selected from the group consisting
5 of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more than 25 at.%.
10

[Claim 7] A semiconductor device having a multilayer structure comprising an first conductive film
10 formed on a principle plane side of a semiconductor substrate, and a silver (Ag) film or a silver (Ag) alloy film formed in contact with said first conductive film, wherein said first conductive film has as a main
15 constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and said first conductive film contains as an added element one kind of element selected from the group consisting
20 of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more than 25 at.%.
25

[Claim 8] A semiconductor device having a multilayer structure comprising an first conductive film
formed on a principle plane side of a semiconductor
25 substrate, and a platinum (Pt) film or a platinum (Pt) alloy film formed in contact with said first conductive film, wherein said first conductive film has osmium (Os) as a main constituent element, and said first conductive

film contains as an added element one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more
5 than 25 at.%.

[Claim 9] A semiconductor device having a multilayer structure comprising on a principle plane side of a semiconductor substrate an insulating film including silicon (Si), a first conductive film formed
10 in contact with said insulating film, and a second conductive film formed in contact with said first conductive film, wherein said second conductive film has copper (Cu) as a main constituent element, said first conductive film has as a main constituent element one
15 kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), said first conductive film contains at least one different kind of element in addition to said main constituent element, a difference
20 between an atomic radius of at least one kind of element among said different kinds of elements and an atomic radius of said main constituent element is not more than 10%, and a bond energy between said different kind of element and silicon (Si) is not less than 1.9 times that
25 of said main constituent element of said first conductive film and silicon (Si).

[Claim 10] A semiconductor device having a multilayer structure comprising on a principle plane

side of a semiconductor substrate an insulating film including silicon (Si), a first conductive film formed in contact with said insulating film, and a second conductive film formed in contact with said first

5 conductive film, wherein said second conductive film has copper (Cu) as a main constituent element, a difference $\{|a_p - a_n|/a_p\} \times 100 = A(\%)$ between a short side a_n in a unit rectangular cell of a closest packed crystal plane formed by said main constituent element of said first

10 conductive film and a short side a_p in a unit rectangular cell of a closest packed crystal plane formed by said copper (Cu) element and a difference $\{|b_p - b_n|/b_p\} \times 100 = B(\%)$ between a long side b_n in the unit rectangular cell of the closest packed crystal plane formed by said

15 main constituent element of said first conductive film and a long side b_p in the unit rectangular cell of the closest packed crystal plane formed by said copper (Cu) element satisfy an inequality $\{A + B \times (a_p/b_p)\} < 13\%$, a melting point of said main constituent element of said

20 first conductive film is not less than 1.4 times that of copper (Cu), said first conductive film contains as an added element at least one different kind of element in addition to said main constituent element, a difference between an atomic radius of at least one kind of added

25 element among said different kinds of elements and an atomic radius of said main constituent element of said first conductive film is not more than 10%, and a bond energy between said added element and silicon (Si) is

not less than 1.9 times that of said main constituent element of said first conductive film and silicon (Si).

[Claim 11] A semiconductor device having a multilayer structure comprising on a principle plane
5 side of a semiconductor substrate an insulating film including silicon (Si), a first conductive film formed in contact with said insulating film, and a second conductive film formed in contact with said first conductive film, wherein a difference $\{|a_p - a_n|/a_p\} \times$
10 $100 = A(\%)$ between a short side a_n in a unit rectangular cell of a closest packed crystal plane formed by said main constituent element of said first conductive film and a short side a_p in a unit rectangular cell of a closest packed crystal plane formed by said main
15 constituent element of said second conductive film and a difference $\{|b_p - b_n|/b_p\} \times 100 = B(\%)$ between a long side b_n in the unit rectangular cell of the closest packed crystal plane formed by said main constituent element of said first conductive film and a long side b_p
20 in the unit rectangular cell of the closest packed crystal plane formed by said main constituent element of said second conductive film satisfy an inequality $\{A + B \times (a_p/b_p)\} < 13\%$, a melting point of said main constituent element of said first conductive film is not
25 less than 1.4 times that of said main constituent element of said second conductive film, said first conductive film contains as an added element at least one different kind of element in addition to said main

constituent element, a difference between an atomic radius of at least one kind of added element among said different kinds of elements and an atomic radius of said main constituent element of said first conductive film is not more than 10%, and a bond energy between said added element and silicon (Si) is not less than 1.9 times that of said main constituent element of said first conductive film and silicon (Si).

[Detailed Description of the Invention]

10 [0001]

[Technical Field Pertinent to the Invention]

The present invention relates to a semiconductor device, and more particularly to a semiconductor device whose wiring structure is formed by a multilayer structure.

15 [0002]

[Prior Art]

In conjunction with trends toward higher integration and higher speed of semiconductor devices in recent years, the copper (Cu) wiring having a lower electrical resistance than the conventional aluminum (Al) wiring has come to be introduced. However, if copper (Cu) atoms are diffused and enter a silicon (Si) substrate or an insulating film, there is a possibility of deteriorating the device characteristics, so that an adjacent conductive film (first conductive film) for preventing the diffusion of the copper (Cu) atoms is formed adjacent to a copper (Cu) film. As materials of

this adjacent conductive film, high-melting-point metals such as titanium nitride (TiN), tungsten (W), and tantalum (Ta) have been studied, as described in Nikkei Microdevices (June 1992 issue, pp. 74 - 77). However, 5 if these materials are used as the adjacent conductive film, their adhesion to the plated film of copper (Cu) used for wiring is weak, so that rhodium (Rh), ruthenium (Ru), iridium (Ir), and osmium (Os) have been proposed in Japanese Patent Application Laid-Open Hei 10-229084 10 (JP-A-10-229084) as materials of the adjacent conductive film for improving the adhesion.

[0003]

[Problem to be solved by the Invention]

In the manufacture of semiconductor devices 15 which are finely patterned for higher integration, since there are cases where chemical mechanical polishing (CMP) is employed as a technique for effecting planarization, it is important to improve adhesion between the respective films formed. However, if 20 rhodium (Rh), ruthenium (Ru), iridium (Ir), or osmium (Os) is used as the material of the adjacent conductive film in the copper (Cu) wiring, the adhesion between copper (Cu) and the adjacent conductive film improves, but there is a problem in that the adhesion between the 25 adjacent conductive film and the insulating film is weak. Further, rhodium (Rh), ruthenium (Ru), iridium (Ir), and osmium (Os) are liable to produce high stress during film formation, possibly causing defects such as

cracks to occur in an adjacent film. Furthermore, with the semiconductor devices which are finely patterned for higher integration, the wiring width becomes narrow, so that there is a problem in that voids and disconnections
5 due to migration are likely to occur.

[0004]

A first object of the invention is to provide a highly reliable semiconductor device. A second object of the invention is to provide a semiconductor device
10 having a wiring structure whose yield is high. A third object of the invention is to provide a semiconductor device having a multilayer structure in which adhesive fracture is difficult to occur by the use of highly adhesive adjacent conductive film materials for both a
15 main conductive film forming the wiring and an insulating film. Further, a fourth object of the invention is to provide a semiconductor device having a multilayer structure in which defects such as cracks are difficult to occur. Furthermore, a fifth object of the
20 invention is to provide a semiconductor device in which voids and disconnections due to migration are difficult to occur.

[0005]

[Means for Solving Problem]

25 The present inventors conducted research strenuously to overcome the above-described problems, and discovered that in a case where a first conductive film for diffusion prevention whose main constituent

elements are titanium nitride (TiN), tungsten (W), and tantalum (Ta) is used adjacent to a second conductive film whose main constituent element is copper (Cu), since the lengths of sides of the unit crystal cells of the first conductive film and copper (Cu) substantially differ, the atomic arrangement becomes disarrayed at the interface between the first conductive film and the second conductive film, and the diffusion of the copper (Cu) atoms becomes active, so that adhesive fracture is liable to occur. The present inventors discovered that, to prevent the adhesive fracture at the interface between the copper (Cu) film and the first conductive film, it suffices to suppress the diffusion of the copper (Cu) atoms by using as the first conductive film material a material whose length of the side of the unit crystal cell (lattice constant) is close to that of copper (Cu), i.e., a material in which the difference in the lattice constant (lattice mismatching) with copper (Cu) is small, and that in a case where the melting point of the first conductive film is low, the diffusion of the element constituting the first conductive film becomes active, and the diffusion of the copper (Cu) atoms is accelerated, so that a material having a high melting point is suitable.

[0006]

Further, the present inventors clarified that it is effective in the improvement of adhesion to copper (Cu) to use as the diffusion-preventing adjacent

conductive film a material whose lattice mismatching with copper (Cu) is small and which has a melting point not less than 1.4 times that of copper (Cu). More specifically, the present inventors clarified that in a
5 multilayer wiring structure comprising a first conductive film and a second conductive film formed in contact with the first conductive film, the diffusion at the main conductive film is suppressed and the adhesion between the first conductive film and the second
10 conductive film improves in a case where the difference $\{|a_p - a_n|/a_p\} \times 100 = A(\%)$ between a short side a_n in a unit rectangular cell of a closest packed crystal plane formed by the main constituent element of the first conductive film and a short side a_p in a unit rectangular
15 cell of a closest packed crystal plane formed by the main constituent element of the second conductive film and the difference $\{|b_p - b_n|/b_p\} \times 100 = B(\%)$ between a long side b_n in the unit rectangular cell of the closest packed crystal plane formed by the main constituent
20 element of the first conductive film and a long side b_p in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the second conductive film satisfy an inequality $\{A + B \times (a_p/b_p)\} < 13\%$, and the melting point of the main
25 constituent element of the first conductive film is not less than 1.4 times that of the main constituent element of the second conductive film. Here, the definitions of the short side a and the long side b of a unit

rectangular cell forming the crystal plane where the atomic density is the largest, i.e., the closest packed crystal plane, in a bulk crystal are shown in Fig. 2, and a and b are referred to herein as lattice constants.

5 The short side a is the closest interatomic distance in a bulk crystal, and is described on page 28 of "Introduction to Solid Physics," 1st Vol., 5th Edition (Charles Kittel). In a crystal having a face-centered cubic structure or a closest packed hexagonal structure,
10 the long side b is about 1.73 times the short side a, and in the case of a crystal having a body-centered cubic structure the long side b is about 1.41 times the short side a. Here, the difference A in the short side a and the difference B in the long side b will be
15 referred to as lattice mismatching. Here, the main constituent element of the film means an element which is contained most in the film. Further, kelvin (K) is used as the unit of temperature.

[0007]

20 The present inventors clarified that in a case where the first conductive film formed of rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt) whose lattice mismatching A and B with copper (Cu) are small enough to satisfy the aforementioned
25 inequality $\{A + B \times (a_p/b_p)\} < 13\%$ and which have melting points not less than 1.4 times that of copper (Cu) is used as the adjacent conductive film for the copper (Cu) wiring, the adhesion between the first conductive film

and the copper (Cu) film improves; however, rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt) have weak bonds with silicon (Si), and since an insulating film containing silicon (Si) is generally amorphous, a strong bond cannot be obtained between the first conductive film and the insulating film containing silicon (Si), so that adhesive fracture is liable to occur. Accordingly, in order to improve the adhesion between the first conductive film and the insulating film while strongly maintaining the adhesion between the first conductive film and the copper (Cu) film, it suffices if an added element which is strongly bonded to silicon (Si) and does not disarray the atomic arrangement of the first conductive film is contained in the first conductive film whose main constituent elements are rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt). The present inventors clarified that the adhesivity between the first conductive film and the insulating film improves in a case where the bond energy between this added element and silicon (Si) is not less than 1.9 times that of the main constituent element of the first conductive film and silicon (Si). Nevertheless, if the difference between the atomic radius of the added element and the atomic radius of the main constituent element such as rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt) becomes not less than 10%, the atomic arrangement of the first conductive film becomes

disarrayed, so that the adhesion between the first
conductive film and the copper (Cu) film becomes weak.
Accordingly, an added element becomes effective in which
the difference between the atomic radius of the added
5 element and the atomic radius of the main constituent
element of the first conductive film is not more than
10%, and whose bond energy with silicon (Si) is not less
than 1.9 times the bond energy between the main
constituent element of the first conductive film and
10 silicon (Si). It was clarified that palladium (Pd),
cobalt (Co), nickel (Ni), and titanium (Ti) are
effective as added elements which satisfy these
conditions. Further, it was clarified that the
inclusion of such added elements is effective in
15 reducing the internal stress in the first conductive
film.

[0008]

Furthermore, the present inventors clarified
that in a case where rhodium (Rh), ruthenium (Ru),
20 iridium (Ir), osmium (Os), and platinum (Pt) whose
lattice mismatching A and B with copper (Cu) are small
enough to satisfy the aforementioned inequality $\{A + B \times (a_p/b_p)\} < 13\%$ and which have melting points not less
than 1.4 times that of copper (Cu) are used as the main
25 constituent elements of the conductive film adjacent to
the copper (Cu) film, the diffusion of the copper (Cu)
atoms is suppressed, and migration resistance improves.

[0009]

Namely, to overcome the problems of the invention of this application, the present inventors discovered that it is important to provide a semiconductor device having a multilayer structure

5 comprising on a principle plane side of a semiconductor substrate an insulating film including silicon (Si), a first conductive film formed in contact with the insulating film, and a second conductive film formed in contact with the first conductive film, wherein a

10 difference $\{|a_p - a_n|/a_p\} \times 100 = A(\%)$ between a short side a_n in a unit rectangular cell of a closest packed crystal plane formed by the main constituent element of the first conductive film and a short side a_p in a unit rectangular cell of a closest packed crystal plane

15 formed by the main constituent element of the second conductive film and a difference $\{|b_p - b_n|/b_p\} \times 100 = B(\%)$ between a long side b_n in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the first conductive film and a

20 long side b_p in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the second conductive film satisfy an inequality $\{A + B \times (a_p/b_p)\} < 13\%$, a melting point of the main constituent element of the first conductive

25 film is not less than 1.4 times that of the main constituent element of the second conductive film, the first conductive film contains as an added element at least one different kind of element in addition to the

main constituent element, a difference between an atomic radius of at least one kind of added element among the different kinds of elements and an atomic radius of the main constituent element of the first conductive film is not more than 10%, and a bond energy between the added element and silicon (Si) is not less than 1.9 times that of the main constituent element of the first conductive film and silicon (Si). More specifically, the invention provides:

10 A semiconductor device having a multilayer structure comprising an insulating film including silicon (Si) formed on a principle plane side of a semiconductor substrate, a first conductive film formed in contact with the insulating film, and a second
15 conductive film formed in contact with the first conductive film, wherein the second conductive film has copper (Cu) as a main constituent element, the first conductive film has as a main constituent element one kind of element selected from the group consisting of at
20 least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and the first conductive film contains as an added element one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti).

25 [0010]

 A semiconductor device having a multilayer structure comprising an insulating film including silicon (Si) formed on a principle plane side of a

semiconductor substrate, a first conductive film formed in contact with the insulating film, and a copper (Cu) film or a copper (Cu) alloy film formed in contact with the first conductive film, wherein the first conductive
5 film has as a main constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and the first conductive film contains as an added element one kind of element
10 selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 10 at.% and not more than 25 at.%.
25

A semiconductor device having a multilayer
15 structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a copper (Cu) film or a copper (Cu) alloy film formed in contact with the first conductive film, wherein the first conductive film has as a main constituent element
20 one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and the first conductive film contains as an added element one kind of element selected from the group consisting of at least palladium
25 (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more than 25 at.%.
30

A semiconductor device having a multilayer

structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a copper (Cu) film or a copper (Cu) alloy film formed in contact with the first conductive film, wherein the

5 first conductive film has as a main constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and the first conductive film contains palladium (Pd) with a concentration of not

10 less than 0.14 at.% and not more than 25 at.%.

A semiconductor device having a multilayer structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a copper (Cu) film or a copper (Cu) alloy film formed in

15 contact with the first conductive film, wherein the first conductive film has as a main constituent material at least one kind of element selected from the group consisting of rhodium oxide, ruthenium oxide, iridium oxide, and osmium oxide, and the first conductive film

20 contains as an added element one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more than 25 at.%.

25 A semiconductor device having a multilayer structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a gold (Au) film or a gold (Au) alloy film formed in

contact with the first conductive film, wherein the first conductive film has as a main constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir),
5 osmium (Os), and platinum (Pt), and the first conductive film contains as an added element one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more
10 than 25 at.%.

A semiconductor device having a multilayer structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a silver (Ag) film or a silver (Ag) alloy film formed in
15 contact with the first conductive film, wherein the first conductive film has as a main constituent element one kind of element selected from the group consisting of at least rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and the first conductive
20 film contains as an added element one kind of element selected from the group consisting of at least palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a concentration of not less than 0.14 at.% and not more than 25 at.%.

25 A semiconductor device having a multilayer structure comprising an first conductive film formed on a principle plane side of a semiconductor substrate, and a platinum (Pt) film or a platinum (Pt) alloy film

formed in contact with the first conductive film,
wherein the first conductive film has osmium (Os) as a
main constituent element, and the first conductive film
contains as an added element one kind of element
5 selected from the group consisting of at least palladium
(Pd), cobalt (Co), nickel (Ni), and titanium (Ti) with a
concentration of not less than 0.14 at.% and not more
than 25 at.%.

A semiconductor device having a multilayer
10 structure comprising on a principle plane side of a
semiconductor substrate an insulating film including
silicon (Si), a first conductive film formed in contact
with the insulating film, and a second conductive film
formed in contact with the first conductive film,
15 wherein the second conductive film has copper (Cu) as a
main constituent element, the first conductive film has
as a main constituent element one kind of element
selected from the group consisting of at least rhodium
(Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and
20 platinum (Pt), the first conductive film contains at
least one different kind of element in addition to the
main constituent element, a difference between an atomic
radius of at least one kind of element among the
different kinds of elements and an atomic radius of the
25 main constituent element is not more than 10%, and a
bond energy between the different kind of element and
silicon (Si) is not less than 1.9 times that of the main
constituent element of said first conductive film and

silicon (Si).

[0011]

[Mode for Carrying Out the Invention]

Hereafter, a more detailed description will be
5 given of the mode for carrying out the invention through
the embodiments shown in the drawings.

First, a cross-sectional structure of
principal portions of a semiconductor device in
accordance with a first embodiment of the invention is
10 shown in Fig. 1. As shown in Fig. 1, in the
semiconductor device of this embodiment, diffusion
layers 2, 3, 4, and 5 are formed on a silicon substrate
1, and gate insulating films 6 and 7 and gate electrodes
8 and 9 are formed thereon, thereby forming a MOS
15 transistor. The gate insulating films 6 and 7 are, for
example, silicon dioxide films or silicon nitride films,
while the gate electrodes 8 and 9 are, for example,
polycrystalline silicon films, metal thin films, or
metal silicide films, or a laminated structure thereof.
20 The MOS transistor is separated by a device separating
film 10 formed of, for example, a silicon dioxide film.
Insulating films 11 and 12, which are formed of, for
example, silicon dioxide films, are formed on top of the
gate electrodes 8 and 9 and on side walls thereof. An
25 insulating film 13, which is formed of, for example, a
boron-doped phospho-silicate glass (BPSG) film, a spin-
on glass (SOG) film, or a silicon dioxide film, a
silicon nitride film, or the like formed by chemical

vapor deposition or sputtering, is formed on the entire surfaces of the upper portions of the MOS transistor. Plugs, which are each formed of a main conductive film 15 coated with adjacent conductive films (first
5 conductive films) 14a and 14b for preventing diffusion, are respectively formed in contact holes formed in the insulating film 13, and are connected to the diffusion layers 2, 3, 4, and 5. A multilayer interconnection, which is formed of a main conductive film 17 coated with
10 adjacent conductive films 16a and 16b for preventing diffusion, is connected through these plugs. This multilayer interconnection can be obtained by a process in which, for instance, grooves for interconnection are formed in an insulating film 18, and after the adjacent
15 conductive film 16a is formed thereon by such as chemical vapor deposition, the main conductive film 17 is formed by such as plating, followed by the formation of the adjacent conductive film 16b thereon by such as chemical vapor deposition. On top of this multilayer
20 interconnection, a plug, which is formed of a main conductive film 20 coated with an adjacent conductive film 19, is formed in a contact hole formed in an insulating film 21, and is connected to the aforementioned multilayer interconnection. A second
25 multilayer interconnection, which is formed of a main conductive film 23 coated with adjacent conductive films 22a and 22b, is connected through this plug. This second multilayer interconnection can be obtained by a

process in which, for instance, grooves for interconnection are formed in an insulating film 24, and after the adjacent conductive film 22a is formed thereon by such as chemical vapor deposition, the main

5 conductive film 23 is formed by such as plating, followed by the formation of the adjacent conductive film 22b thereon by such as chemical vapor deposition.

[0012]

In this embodiment, with respect to at least
10 one set among the main conductive film 15 coated with the adjacent conductive films 14a and 14b, the main conductive film 17 coated with the adjacent conductive films 16a and 16b, the main conductive film 20 coated with the adjacent conductive film 19, and the main
15 conductive film 23 coated with the adjacent conductive films 22a and 22b, the constituent elements of the adjacent conductive film are selected such that all of the following requirements are met: that the difference $\{|a_p - a_n|/a_p\} \times 100 = A(\%)$ between a short side a_n in a
20 unit rectangular cell of a closest packed crystal plane formed by a main constituent element of the adjacent conductive film and a short side a_p in a unit rectangular cell of a closest packed crystal plane formed by a main constituent element of the main conductive film and the
25 difference $\{|b_p - b_n|/b_p\} \times 100 = B(\%)$ between a long side b_n in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the adjacent conductive film and a long side

b_p in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the main conductive film satisfy the inequality $\{A + B \times (a_p/b_p)\} < 13\%$, that the melting point of the main

5 constituent element of the adjacent conductive film is not less than 1.4 times that of the main constituent element of the main conductive film, that the adjacent conductive film contains at least one different kind of element in addition to the main constituent element,

10 that the difference between the atomic radius of at least one kind of added element among the different kinds of elements and the atomic radius of the main constituent element of the adjacent conductive film is not more than 10%, and that the bond energy between the

15 added element and silicon (Si) is not less than 1.9 times that of the main constituent element of the adjacent conductive film and silicon (Si).

Specifically, in a case where the copper (Cu) film is used as the main conductive film, it suffices if the

20 adjacent conductive film has as its main constituent element at least one kind of element selected from rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and contains as an added element at least one kind of element selected from palladium (Pd),

25 cobalt (Co), nickel (Ni), and titanium (Ti). The film which is formed of rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), or platinum (Pt) and contains such an added element is formed by, for instance, chemical vapor

deposition, plating, or sputtering.

[0013]

Hereafter, a description will be given of the effects of the semiconductor device in accordance with this embodiment. Since the effects of improvement of adhesion include the following two effects, a description will be given in two parts. The first effect is that the adhesion between the adjacent conductive film and the main conductive film is improved by providing settings such that the lattice mismatching A and B between the main constituent element of the adjacent conductive film and that of the main conductive film satisfies the aforementioned inequality $\{A + B \times (a_p/b_p)\} < 13\%$, and that the melting point of the main constituent element of the adjacent conductive film is not less than 1.4 times that of the main constituent element of the main conductive film. The second effect is that the adhesion between the adjacent conductive film and the insulating film including silicon (Si) is improved while maintaining the adhesion between the adjacent conductive film and the main conductive film, by providing settings such that the following requirements are met: that the adjacent conductive film contains at least one different kind of element in addition to the main constituent element, that the difference between the atomic radius of at least one kind of added element among the different kinds of elements and the atomic radius of the main constituent

element of the adjacent conductive film is not more than 10%, and that the bond energy between the added element and silicon (Si) is not less than 1.9 times that of the main constituent element of the adjacent conductive film
5 and silicon (Si).

[0014]

First, a detailed description will be given of the first effect of improvement of adhesion. By taking note of the lattice mismatching A and B between the main
10 constituent element of the adjacent conductive film and that of the main conductive film, the present inventors examined the effect of this difference exerted on the adhesive fracture energy U through a molecular dynamic simulation. The molecular dynamic simulation is a
15 method in which, as described on pages 4864 through 4878 in Vol. 54 (published in 1983) of the Journal of Applied Physics, for example, the force acting in each atom through interatomic potential is calculated, and the position of each atom at each time is calculated by
20 solving Newton's equation of motion on the basis of this force. The adhesive fracture energy U indicates energy necessary for allowing adhesive fracture to take place between the adjacent conductive film and the main conductive film, and is described on pages 45 through 70
25 of Vol. 66 (published in 1994) of the International Journal of Fracture, for example. In this example of simulation, U is calculated by subtracting the aggregate sum of the interatomic potential inside a system in

which the adjacent conductive film is connected to the main conductive film from the amount in which the aggregate sum of the interatomic potential in the main conductive film is added to the aggregate sum of the interatomic potential in the adjacent conductive film. As an example, shown below is the result of simulation in the case where the main conductive film is the copper (Cu) film. In this case, the closest packed crystal plane of copper (Cu) having a face-centered cubic lattice is the (111) plane, the lattice constant a_p is approximately 0.26 nm, and the lattice constant b_p is approximately 0.44 nm.

[0015]

In the example of simulation shown here, at a temperature of 900 K, constituent atoms of the adjacent conductive film were deposited on an SiO_2 film having a thickness of 3 nm, and Cu atoms were then deposited thereon, thereby forming an adjacent conductive film with a thickness of 3 nm and a Cu film with a thickness of 3 nm. Subsequently, the temperature was lowered to 300 K. In this state, the adhesive fracture energy U was calculated by subtracting the aggregate sum of the interatomic potential inside a system comprising both the adjacent conductive film and the Cu film from the amount in which the aggregate sum of the interatomic potential in the Cu film was added to the aggregate sum of the interatomic potential in the adjacent conductive film. In the molecular dynamic simulation, by varying

the depth of the interatomic potential of the constituent element of the adjacent conductive film, it is possible to vary the melting point of the adjacent conductive film while maintaining the lattice constant of the adjacent conductive film at a fixed level. As a result of varying the melting point of the adjacent conductive film while maintaining the lattice constant of the adjacent conductive film at the same levels as those of Ru and Pt, it was found that when the melting point of the adjacent conductive film is not less than 1.4 times that of copper (Cu), the adhesive fracture energy U is substantially not dependent on the melting point of the adjacent conductive film, as shown in Fig. 3. Furthermore, it was also found that, as can be seen from Fig. 3, when the melting point of the adjacent conductive film becomes smaller than 1.4 times that of copper (Cu), the adhesive fracture energy U becomes small, and the adhesive fracture strength becomes weak. In Fig. 3, U_{Cu} denotes the adhesive fracture energy between the copper (Cu) film and the copper (Cu) film. It was also found that when the melting point of the adjacent conductive film is not less than 1.4 times that of copper (Cu), the adhesive fracture energy U is not dependent on the lattice mismatching A and B , as shown in Figs. 4 and 5. Fig. 4 is obtained by preparing a map in which the lattice mismatching A is taken as the abscissa and the amount in which the lattice mismatching B is multiplied by (a_p/b_p) is taken as the ordinate, by

setting the values of A and B so as to cover this map,
and by calculating the value of the adhesive fracture
energy U by the molecular dynamic simulation. In Fig.
4, the region on the inner side of the boundary line,
5 i.e., the region close to the origin, is a region where
the adhesive fracture energy U is greater than 0.5 time
 U_{Cu} , and the adhesive fracture is unlikely to occur
between the adjacent conductive film and the copper (Cu)
film. Here, U_{Cu} denotes the adhesive fracture energy
10 between the copper (Cu) film and the copper (Cu) film.
In Fig. 4, the region on the outer side of the boundary
line is a region where the adhesive fracture energy U is
smaller than 0.5 time U_{Cu} , and the adhesive fracture is
likely to occur between the adjacent conductive film and
15 the copper (Cu) film. Fig. 5 shows the result of
conducting examination of the change of adhesive
fracture energy along the broken line in Fig. 4 to
closely study the lattice mismatching dependence of the
adhesive fracture energy U. Referring to Fig. 5, since
20 the adhesive fracture energy changes sharply in the
vicinity of $U/U_{Cu} = 0.5$, the adhesive fracture prevention
effect becomes noticeable by using this level as a
boundary. It can be seen that titanium nitride (TiN)
and the like, whose adhesive fracture with respect to
25 copper (Cu) has been a problem, are located on the side
where U/U_{Cu} is smaller than 0.5. Fig. 4 reveals that
tungsten (W) and tantalum (Ta) are also located outside
the boundary line of $U/U_{Cu} = 0.5$. Meanwhile, rhodium

(Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt) are located on the inner side, i.e., on the origin side, of the boundary line in Fig. 4, and it can be seen that these elements are effective in the improvement of adhesion to the copper (Cu) film. If the boundary line in Fig. 4 is linearly approximated, the boundary line can be expressed as $\{A + B \times (a_p/b_p)\} = 13\%$, so that it can be said that the adhesion between the adjacent conductive film and the copper (Cu) film is strong when the inequality $\{A + B \times (a_p/b_p)\} < 13\%$ is satisfied. Nevertheless, even if this inequality is satisfied, it can be seen from Fig. 3 that in a case where the melting point of the main constituent element of the adjacent conductive film is smaller than 1.4 times that of copper (Cu), the diffusion of the element constituting the adjacent conductive film becomes active and accelerates the diffusion of the copper (Cu) atoms, so that the adhesive fracture energy U becomes small, and the adhesive fracture is liable to take place between the adjacent conductive film and the copper (Cu) film. For example, in the case of nickel (Ni) having a melting point which is 1.27 times the melting point of copper (Cu), 1358 K, the lattice mismatching A and B with copper (Cu) is $\{A + B \times (a_p/b_p)\} = 4\%$, and although the aforementioned inequality $\{A + B \times (a_p/b_p)\} < 13\%$ is satisfied, the adhesive fracture energy is small at $0.4 U_{Cu}$, and the adhesion does not improve. The effect of this embodiment seen in the result of the above-

described simulation can be demonstrated even if the simulation conditions such as the temperature and the film thickness are changed.

[0016]

5 In this embodiment, since settings are provided such that the lattice mismatching A and B between the adjacent conductive film and the main conductive film satisfies the aforementioned inequality $\{A + B \times (a_p/b_p)\} < 13\%$, and that the melting point of
10 the main constituent element of the adjacent conductive film is not less than 1.4 times that of the main constituent element of the main conductive film, the adhesion between the adjacent conductive film and the main conductive film is strong. This effect is
15 particularly noticeable in the case where the main conductive film is the Cu film formed by plating or CVD.

[0017]

Next, a description will be given of the aforementioned second effect of improvement of adhesion.
20 The present inventors examined through a molecular dynamic simulation how the adhesive fracture energy between the adjacent conductive film and the insulating film changes by the added element contained in the adjacent conductive film. Fig. 6 is a graph
25 illustrating the change of the adhesive fracture energy with respect to the concentration of palladium (Pd) in a case where a simulation was performed in which, as an example, films, which contained palladium (Pd) as an

added element in the adjacent conductive films respectively composed of rhodium (Rh), ruthenium (Ru), and platinum (Pt), were formed on the SiO_2 film at 900 K, and were allowed to cool to 300 K. The film thickness
5 was set to 3 nm for both the adjacent conductive film and the SiO_2 film. The adhesive fracture energy occurring here is the energy necessary for causing adhesive fracture between the adjacent conductive film and the silicon dioxide film (SiO_2 film). This graph
10 reveals that if the concentration of palladium (Pd) becomes approximately 10 at.% (atomic percent) or more, the adhesive fracture energy increases sharply, and the adhesion between the adjacent conductive film and the silicon dioxide film (SiO_2 film) improves. Similarly,
15 Fig. 7 shows the change of the adhesive fracture energy with respect to the concentration of titanium (Ti) in a case where titanium (Ti) was contained as an added element in the adjacent conductive films respectively composed of rhodium (Rh), ruthenium (Ru), and platinum
20 (Pt). It can be seen from this graph that, also in the case where the added element is titanium (Ti), if the concentration becomes approximately 10 at.% or more, the adhesive fracture energy increases sharply, improving the adhesion between the adjacent conductive film and
25 the silicon dioxide film (SiO_2 film). From Figs. 6 and 7, it can be seen that if the concentration of the added element becomes approximately 15 at.%, the adhesive fracture energy becomes substantially fixed, and the

effect of improvement of adhesion becomes saturated.

Next, Fig. 8 shows a graph in which the bond energy between the added element and silicon (Si) is taken as the abscissa, and the adhesive fracture energy in a case

5 where the concentration of the added element was set to 20 at.% is taken as the ordinate, to examine what added elements improve the adhesion to the silicon dioxide film (SiO_2 film). In this graph, $E_{\text{B-Si}}$ on the abscissa represents the bond energy between the main constituent

10 element of the adjacent conductive film and silicon (Si). From Fig. 8, it was found that an added element whose bond energy with silicon (Si) is not less than approximately 1.9 times that of the main constituent element of the adjacent conductive film and silicon (Si)

15 improves the adhesion to the silicon dioxide film (SiO_2 film). Specifically, palladium (Pd), cobalt (Co), nickel (Ni), titanium (Ti), hafnium (Hf), and zirconium (Zr) are effective in the improvement of adhesion to the silicon dioxide film (SiO_2 film). However, in a case

20 where the adhesion between the adjacent conductive film and the copper (Cu) film becomes weak due to the fact that the added element is contained in the adjacent conductive film, such elements are not suitable as the added elements, so that elements corresponding to such a

25 case must be eliminated. Hereafter, a description will be given of the effect of the added element on the adhesion to the copper (Cu) film. As shown in Figs. 4 and 5, the adhesion between the adjacent conductive film

and the copper (Cu) film improves by using as the main constituent element of the adjacent conductive film rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), or platinum (Pt) whose lattice mismatching with copper
5 (Cu) is small, so that it can be said that an added element which does not make this lattice mismatching large is suitable. Namely, it is important not to disarray the atomic arrangement of rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum
10 (Pt), and an added element whose atomic radius is close to their atomic radii is suitable. To closely examine this state, the influence of the added element on the adhesion to the copper (Cu) film was examined by taking as an example the case in which ruthenium (Ru) was used
15 as the main constituent element of the adjacent conductive film, and by taking as the abscissa the difference in the atomic radius between the added element and ruthenium (Ru) and by taking as the ordinate the adhesive fracture energy between the ruthenium (Ru)
20 film and the copper (Cu) film. The result is shown in Fig. 9. As can be seen from the graph, added elements whose differences in the atomic radius are not less than 10% weaken the adhesion to the copper (Cu) film even if their concentrations are not more than 20 at.%.
25 Specifically, hafnium (Hf) and zirconium (Zr) correspond to this case. Although these elements have large bond energies with silicon (Si) as shown in Fig. 8, and are effective in the improvement of adhesion to the silicon

dioxide film (SiO_2 film), their differences in the atomic radius with ruthenium (Ru) are large, and disarrays the atomic arrangement of ruthenium (Ru), so that they weaken the adhesion to the copper (Cu) film. By taking
5 into consideration both Figs. 8 and 9, as added elements for improving the adhesion between the silicon dioxide film (SiO_2 film) and the ruthenium (Ru) film while strongly maintaining the adhesion between the copper (Cu) film and the ruthenium (Ru) film, it is possible to
10 cite palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) whose differences in the atomic radius with ruthenium (Ru) are not more than 10%, and whose bond energies with silicon (Si) are not less than 1.9 times the bond energy between ruthenium (Ru) and silicon
15 (Si). Since rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt) respectively have atomic radii close to that of ruthenium (Ru), it is possible to cite similar added elements for them as well. Fig. 9 reveals that in the case where palladium (Pd), cobalt
20 (Co), nickel (Ni), and titanium (Ti) are added, the adhesion to the copper (Cu) film becomes weak if the concentration becomes 30 at.% or more. By taking into consideration both Figs. 6 and 7, the concentrations of palladium (Pd), cobalt (Co), nickel (Ni), and titanium
25 (Ti) are preferably not less than 10 at.% and not more than 25 at.%. The effect of this embodiment seen in the result of the above-described simulation can be demonstrated even if the simulation conditions such as

the temperature and the film thickness are changed.

[0018]

Another effect of the semiconductor device in accordance with the first embodiment of the invention is that the stress in the adjacent conductive films 14, 16, 19, 22a, and 22b is reduced by the inclusion of the added element, and therefore defects such as cracks become difficult to occur. An examination was made through a molecular dynamic simulation as to how the internal stress in the adjacent conductive film changes due to the added element contained in the adjacent conductive film. Fig. 10 is a graph illustrating the change of the internal stress S remaining in the Ru film with respect to the concentration of the added element in a case where a simulation was performed in which, as an example, films, which respectively contained palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) as added elements in ruthenium (Ru), were formed on the SiO_2 film at 900 K, and were allowed to cool to 300 K. The film thickness was set to 3 nm for both the Ru film and the SiO_2 film. In Fig. 10, S_0 denotes the internal stress in the case where the added element was not contained. From Fig. 10, it can be seen that the internal stress is reduced if the concentrations of the added elements are not less than approximately 0.14 at.%. Fig. 10 reveals that, of these four elements, nickel (Ni) and cobalt (Co) having lower melting points are particularly effective in the reduction of the

internal stress. Since palladium (Pa) and titanium (Ti) have fairly lower melting points than ruthenium (Ru), their effect of reducing the internal stress is shown in Fig. 10. In a case where tungsten (W) and tantalum (Ta) whose melting points are higher than ruthenium (Ru) are added for comparison's sake, the internal stress increases together with the concentration of the added element as shown in Fig. 11, so that it can be seen that these elements are not effective in the reduction of the internal stress. By also taking Fig. 9 into consideration, it can be said that the concentrations of the added elements, palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti), are preferably not less than 0.14 at.% and not more than 25 at.%. The effect of this embodiment seen in the result of the above-described simulation can be demonstrated even if the simulation conditions such as the temperature and the film thickness are changed.

[0019]

Still another effect of the semiconductor device in accordance with the first embodiment of the invention is that the electromigration resistance of the conductor film improves. As an example, a description will be given of the effect in the case where the main conductive film is the copper (Cu) film. Although, in Fig. 5 referred to before, the effect of the lattice mismatching exerted on the adhesive fracture energy is obtained as a result of the molecular dynamic

simulation, it is possible to examine the effect of the lattice mismatching exerted on the diffusion coefficient of the copper (Cu) atom through a simulation similar thereto. Fig. 12 shows a graph in which the lattice mismatching A is taken as the abscissa and the diffusion coefficient of the copper (Cu) atom is taken as the ordinate in the same way as Fig. 5. It should be noted, however, that D denotes the diffusion coefficient of the copper (Cu) atom in the copper (Cu) film having the adjacent conductive film as a substrate, and D_0 denotes a diffusion coefficient in bulk copper (Cu). It can be seen that if the lattice mismatching becomes greater than the boundary line, the diffusion coefficient increases sharply, and the copper (Cu) atoms exhibit the tendency of mobility. If the atoms are mobile, voids and disconnections are liable to occur such as when the current has flowed; Namely, migration resistance becomes low. On the other hand, in a region where the diffusion coefficient is small, the atoms are less mobile, so that it can be said that the migration resistance excels. As can be seen from the graph, rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt) are included in the region where the diffusion coefficient is small. Accordingly, in this embodiment, since rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt) whose lattice mismatching with copper (Cu) is small are used as the main constituent elements of the conductor film adjacent to the conductor film

having copper (Cu) as the main constituent element, the migration resistance improves.

[0020]

As an effect of the embodiment other than
5 those described above, in the case where the copper (Cu) film is used as the main conductive film, the adjacent conductive film has as its main constituent element at least one kind of element selected from rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum
10 (Pt), and contains as an added element at least one kind of element selected from palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti), so that the copper (Cu) atoms in the adjacent conductive film become difficult to be diffused, thereby improving the reliability of the
15 semiconductor device.

[0021]

Although, in this embodiment, an example has been shown in which in the case where the copper (Cu) film is used as the main conductive film, the adjacent
20 conductive film is a film which has as its main constituent element at least one kind of element selected from rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and contains as an added element at least one kind of element selected from
25 palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti), the advantages of this embodiment can be obtained even if the adjacent conductive film contains other additional elements apart from these elements.

Furthermore, the adjacent conductive film may be a film which has as its main constituent material at least one material selected from rhodium oxide, ruthenium oxide, iridium oxide, and osmium oxide, and may contain as an
5 added element at least one kind of element selected from palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti). In addition, even if this adjacent conductive film contains other added elements apart from these elements, the effects of this embodiment can be
10 obtained.

[0022]

Next, Fig. 13 shows a cross-sectional structure of principal portions of a semiconductor device in accordance with a second embodiment of the
15 invention. The difference of the second embodiment from the first embodiment lies in that although the side walls of the main conductive film 17 and the side walls of the main conductive film 23 in the first embodiment are not coated, the side walls of the main conductive
20 film 17 and the side walls of the main conductive film 23 in the second embodiment are respectively coated with adjacent conductive films 16c and adjacent conductive films 22c. Consequently, the structure provided is such that the constituent elements of the main conductive
25 films 17 and 23 are prevented from becoming dispersed from the side walls to the insulating films 18 and 24.

[0023]

Next, Fig. 14 shows a cross-sectional

structure of principal portions of a semiconductor device in accordance with a third embodiment of the invention. The differences of the third embodiment from the first embodiment lie in that the interconnection layer formed by the main conductive film 17 is connected to an uncoated conductive plug 26, and that the interconnection layer formed by the main conductive film 23 is connected to an uncoated conductive plug 27. Since these conductive plugs 26 and 27 are respectively in contact with the main conductive films 17 and 23 and the insulating films 13 and 21, to improve the reliability it suffices if the constituent elements of the conductive plug 26 are selected such that all of the following requirements are met: that the difference $\{|a_p - a_n|/a_p\} \times 100 = A(\%)$ between the short side a_n in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the conductive plug 26 and the short side a_p in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the main conductive film 17 and the difference $\{|b_p - b_n|/b_p\} \times 100 = B(\%)$ between the long side b_n in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the conductive plug 26 and the long side b_p in the unit rectangular cell of the closest packed crystal plane formed by the main constituent element of the main conductive film 17 satisfy the inequality $\{A + B \times (a_p/b_p)\} < 13\%$, that the

melting point of the main constituent element of the
conductive plug 26 is not less than 1.4 times that of
the main constituent element of the main conductive film
17, that the conductive plug 26 contains at least one
5 different kind of element in addition to the main
constituent element, that the difference between the
atomic radius of at least one kind of added element
among the different kinds of elements and the atomic
radius of the main constituent element of the conductive
10 plug 26 is not more than 10%, and that the bond energy
between the added element and silicon (Si) is not less
than 1.9 times that of the main constituent element of
the conductive plug 26 and silicon (Si). Specifically,
in a case where the main conductive film 17 has the
15 copper (Cu) film as its main constituent element, it
suffices if the conductive plug 26 has as its main
constituent element at least one kind of element
selected from rhodium (Rh), ruthenium (Ru), iridium
(Ir), osmium (Os), and platinum (Pt), and contains as an
20 added element at least one kind of element selected from
palladium (Pd), cobalt (Co), nickel (Ni), and titanium
(Ti). Similarly, to improve the adhesion between the
conductive film plug 27 and the main conductive film 23
and the adhesion between the conductive film plug 27 and
25 the insulating film 21, it suffices if the constituent
elements of the conductive plug 27 are selected such
that all of the following requirements are met: that
the difference $\{ |a_p - a_n| / a_p \} \times 100 = A(\%)$ between the

short side a_n in the unit rectangular cell of the closest
 packed crystal plane formed by the main constituent
 element of the conductive plug 27 and the short side a_p
 in the unit rectangular cell of the closest packed
 5 crystal plane formed by the main constituent element of
 the main conductive film 23 and the difference $\{|b_p -$
 $b_n|/b_p\} \times 100 = B(\%)$ between the long side b_n in the unit
 rectangular cell of the closest packed crystal plane
 formed by the main constituent element of the conductive
 10 plug 27 and the long side b_p in the unit rectangular cell
 of the closest packed crystal plane formed by the main
 constituent element of the main conductive film 17
 satisfy the inequality $\{A + B \times (a_p/b_p)\} < 13\%$, that the
 melting point of the main constituent element of the
 15 conductive plug 27 is not less than 1.4 times that of
 the main constituent element of the main conductive film
 23, that the conductive plug 27 contains at least one
 different kind of element in addition to the main
 constituent element, that the difference between the
 20 atomic radius of at least one kind of added element
 among the different kinds of elements and the atomic
 radius of the main constituent element of the conductive
 plug 27 is not more than 10%, and that the bond energy
 between the added element and silicon (Si) is not less
 25 than 1.9 times that of the main constituent element of
 the conductive plug 27 and silicon (Si). Specifically,
 in a case where the main conductive film 23 has the
 copper (Cu) film as its main constituent element, it

suffices if the conductive plug 27 has as its main constituent element at least one kind of element selected from rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and contains as an added element at least one kind of element selected from palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti). As a result, since the conductive plugs 26 and 27 are provided with melting points higher than those of the main conductive films 17 and 23, the structure excels in thermal resistance and migration resistance. Although, in Fig. 14, the case has been shown in which the conductive plugs 26 and 27 are respectively brought into direct contact with the insulating films 13 and 21, the structure may be such that an intermediate film is formed between the conductive plug 26 and the insulating film 13 and between the conductive plug 27 and the insulating film 21.

[0024]

Further, Fig. 15 shows a cross-sectional structure of principal portions of a semiconductor device in accordance with a fourth embodiment of the invention. The difference of the fourth embodiment from the first embodiment lies in that the interconnection layer formed by the main conductive film 17 is connected via a conductive plug 32 to a gate electrode 29 formed on a gate insulating film 28. In this case, since the gate electrode 29 is in contact with the conductor plug 29 and an insulating film 30, to improve the reliability

it suffices if the constituent elements of the gate
 electrode 29 are selected such that all of the following
 requirements are met: that the difference $\{|a_p - a_n|/a_p\}$
 $\times 100 = A(\%)$ between the short side a_n in the unit
 5 rectangular cell of the closest packed crystal plane
 formed by the main constituent element of the gate
 electrode 29 and the short side a_p in the unit
 rectangular cell of the closest packed crystal plane
 formed by the main constituent element of the conductive
 10 plug 32 and the difference $\{|b_p - b_n|/b_p\} \times 100 = B(\%)$
 between the long side b_n in the unit rectangular cell of
 the closest packed crystal plane formed by the main
 constituent element of the gate electrode 29 and the
 long side b_p in the unit rectangular cell of the closest
 15 packed crystal plane formed by the main constituent
 element of the conductive plug 32 satisfy the inequality
 $\{A + B \times (a_p/b_p)\} < 13\%$, that the melting point of the
 main constituent element of the gate electrode 29 is not
 less than 1.4 times that of the main constituent element
 20 of the conductive plug 32, that the gate electrode 29
 contains at least one different kind of element in
 addition to the main constituent element, that the
 difference between the atomic radius of at least one
 kind of added element among the different kinds of
 25 elements and the atomic radius of the main constituent
 element of the gate electrode 29 is not more than 10%,
 and that the bond energy between the added element and
 silicon (Si) is not less than 1.9 times that of the main

constituent element of the gate electrode 29 and silicon (Si). Specifically, in a case where the conductive plug 32 has the copper (Cu) film as its main constituent element, it suffices if the gate electrode 29 has as its
5 main constituent element at least one kind of element selected from rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and contains as an added element at least one kind of element selected from palladium (Pd), cobalt (Co), nickel (Ni), and titanium
10 (Ti).

[0025]

Next, Fig. 16 shows a cross-sectional structure of principal portions of a semiconductor device in accordance with a fifth embodiment of the
15 invention. The difference of the fifth embodiment from the fourth embodiment lies in that the gate electrode has a laminated structure comprised of the conductive film 29 and a conductive film 33. The conductive film 29 has interfaces of contact with the conductive plug 32
20 and the conductive film 33. For example, in a case where the conductive film 33 is formed of polycrystalline silicon, and the conductive plug 32 has copper (Cu) as its main constituent element, to improve the reliability it suffices if the conductive film 29
25 has as its main constituent element at least one kind of element selected from rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), and platinum (Pt), and contains as an added element at least one kind of

element selected from palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti).

[0026]

Next, Fig. 17 shows a cross-sectional structure of principal portions of a semiconductor device in accordance with a sixth embodiment of the invention. The differences of the sixth embodiment from the first embodiment lie in that the structure provided is such that the adjacent conductive films 14a and 14b are respectively in contact with adjacent conductive films 34a and 34b, and that the adjacent conductive films 16a and 16b are respectively in contact with adjacent conductive films 35a and 35b. As the adjacent films 34a, 34b, 16a, 16b, 16a, and 16b, a conductive film such as titanium nitride (TiN), tantalum (Ta), tantalum nitride (TaN), palladium (Pd), cobalt (Co), nickel (Ni), titanium (Ti), or the like, or an insulating film such as a silicon nitride film is used. Consequently, the structure provided is such that, as compared with the first embodiment, the constituent elements of the main conductive films 15 and 17 can be prevented more powerfully from being dispersed to the insulating films 13 and 18 and the like.

[0027]

As described above, as the main constituent elements of the adjacent conductive films, rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), platinum (Pt), and the like are suitable, but ruthenium (Ru), in

particular, excels among them in terms of workability. In addition, palladium (Pd), cobalt (Co), nickel (Ni), titanium (Ti), and the like are suitable as the added elements, but since, of these four added elements,

5 palladium (Pd) has the smallest difference in the atomic radius with ruthenium (Ru) as shown in Fig. 9, palladium (Pd) is unlikely to disarray the atomic arrangement of ruthenium (Ru) and excels in that it does not increase the electrical resistance even when added. Thus it can

10 be said that palladium (Pd) is the most suitable added element in the case where ruthenium (Ru) is used as the main constituent element of the adjacent conductive film. Further, as shown in Fig. 8, titanium (Ti) has the largest bond energy with silicon (Si), and is most

15 effective in the improvement of adhesion to the insulating film containing silicon (Si). In addition, nickel (Ni) and cobalt (Co) are most effective in reducing the internal stress, as shown in Fig. 10.

[0028]

20 In addition, as for the portion which has been described by citing copper (Cu) as an example, even if gold (Au) or silver (Ag) is used instead of copper (Cu), the above-described effects can be obtained by using rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os),

25 or platinum (Pt) as the main constituent element of the adjacent film. Further, in the case where platinum (Pt) having a high melting point is used instead of copper (Cu), if osmium is used instead of using rhodium (Rh),

ruthenium (Ru), iridium (Ir), osmium (Os), or platinum (Pt), the above-described effects can be obtained.

[0029]

[Advantages of the Invention]

5 In accordance with the invention, since the
adhesion between the adjacent conductive film and the
insulating film can be improved, it is possible to
provide a highly reliable semiconductor device in which
adhesive fracture is difficult to occur. In addition,
10 it is possible to provide a highly reliable
semiconductor device in which defects such as cracks are
difficult to occur in the multilayer structure.
Furthermore, it is possible to provide a highly reliable
semiconductor device in which voids and disconnections
15 due to migration are difficult to occur.

[Brief Description of the Drawings]

[Fig. 1] Fig. 1 is a cross-sectional view of
principal portions of a semiconductor device in
20 accordance with a first embodiment of the invention.

[Fig. 2] Fig. 2 is a diagram illustrating the atomic
arrangement in a closest packed crystal plane and
lattice constants a and b of a unit rectangular cell.

[Fig. 3] Fig. 3 is a diagram illustrating the
25 melting-point dependence of the adhesive fracture energy
between the adjacent conductive film and the main
conductive film in a case where a copper (Cu) film was
used as the main conductive film.

[Fig. 4] Fig. 4 is a diagram illustrating the lattice mismatching dependence of the adhesive fracture energy between the adjacent conductive film and the main conductive film in the case where the copper (Cu) film
5 was used as the main conductive film.

[Fig. 5] Fig. 5 is a diagram illustrating along the broken line in Fig. 4 the lattice mismatching dependence of the adhesive fracture energy between the adjacent conductive film and the main conductive film in the case
10 where the copper (Cu) film was used as the main conductive film.

[Fig. 6] Fig. 6 is a diagram illustrating the dependence of the adhesive fracture energy between the adjacent conductive film and the silicon dioxide film on
15 the concentration of palladium (Pd) in a case where palladium (Pd) was contained as an added element in the adjacent conductive films respectively composed of rhodium (Rh), ruthenium (Ru), and platinum (Pt).

[Fig. 7] Fig. 7 is a diagram illustrating the
20 dependence of the adhesive fracture energy between the adjacent conductive film and the silicon dioxide film on the concentration of titanium (Ti) in a case where titanium (Ti) was contained as an added element in the adjacent conductive films respectively composed of
25 rhodium (Rh), ruthenium (Ru), and platinum (Pt).

[Fig. 8] Fig. 8 is a diagram illustrating the dependence of the adhesive fracture energy between the adjacent conductive film and the silicon dioxide film on

the bond energy between the added element and silicon (Si) in a case where the concentration of the added element was set to 20 at.%.

[Fig. 9] Fig. 9 is a diagram illustrating the
5 dependence of the adhesive fracture energy between a ruthenium (Ru) film and the copper (Cu) film on the difference in the atomic radius between the added element and ruthenium (Ru) in a case where ruthenium (Ru) was used as the main constituent element of the
10 adjacent conductive film.

[Fig. 10] Fig. 10 is a diagram illustrating the dependence of the internal stress in the ruthenium (Ru) film on the concentration of the added element in a case where ruthenium (Ru) film was used as the main
15 constituent element of the adjacent conductive film and palladium (Pd), cobalt (Co), nickel (Ni), and titanium (Ti) were respectively used as the added elements.

[Fig. 11] Fig. 11 is a diagram illustrating the dependence of the internal stress in the ruthenium (Ru)
20 film on the concentration of the added element in a case where ruthenium (Ru) film was used as the main constituent element of the adjacent conductive film and tungsten (W) and tantalum (Ta) were respectively used as the added elements.

25 [Fig. 12] Fig. 12 is a diagram illustrating along the broken line in Fig. 4 the effect of lattice mismatching exerted on the diffusion coefficient of the copper (Cu) atom in the case where the copper (Cu) film

was used as the main conductive film.

[Fig. 13] Fig. 13 is a cross-sectional view of principal portions of a semiconductor device in accordance with a second embodiment of the invention.

5 [Fig. 14] Fig. 14 is a cross-sectional view of principal portions of a semiconductor device in accordance with a third embodiment of the invention.

[Fig. 15] Fig. 15 is a cross-sectional view of principal portions of a semiconductor device in
10 accordance with a fourth embodiment of the invention.

[Fig. 16] Fig. 16 is a cross-sectional view of principal portions of a semiconductor device in accordance with a fifth embodiment of the invention.

[Fig. 17] Fig. 17 is a cross-sectional view of
15 principal portions of a semiconductor device in accordance with a sixth embodiment of the invention.

[Description of Reference Numerals]

1: silicon substrate
2, 3, 4, 5: diffusion layer
6, 7, 28: gate insulating film
8, 9, 29: gate electrode
10: device separating film
11, 12, 13, 18, 21, 24, 25, 30: insulating film
14a, 14b, 16a, 16b, 16c, 19, 22a, 22b, 22c, 31: adjacent
conductive film
15, 17, 20, 23: main conductive film
26, 27, 32: conductive plug

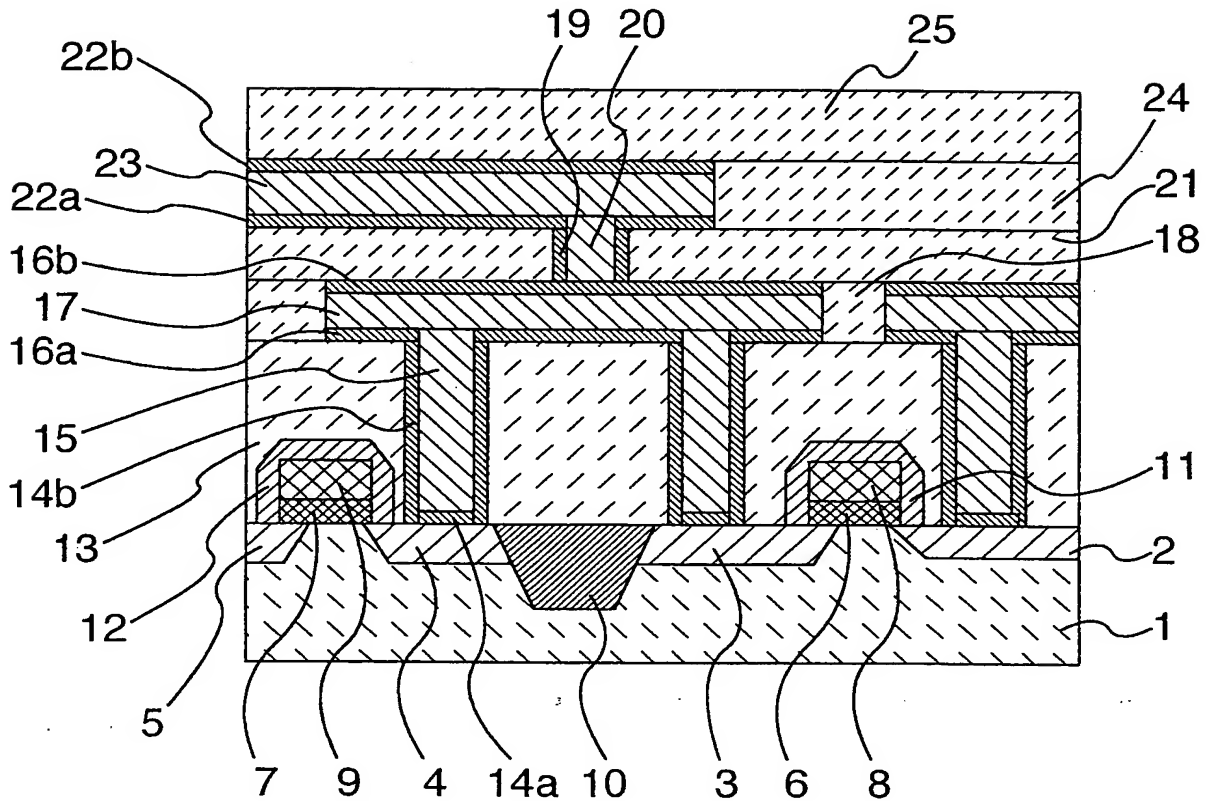
33: conductive film

34a, 34b, 35a, 35b: adjacent film

[Kind of Document] Drawings

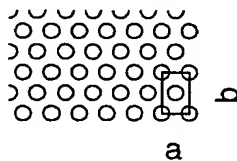
[Fig. 1]

FIG.1



[Fig. 2]

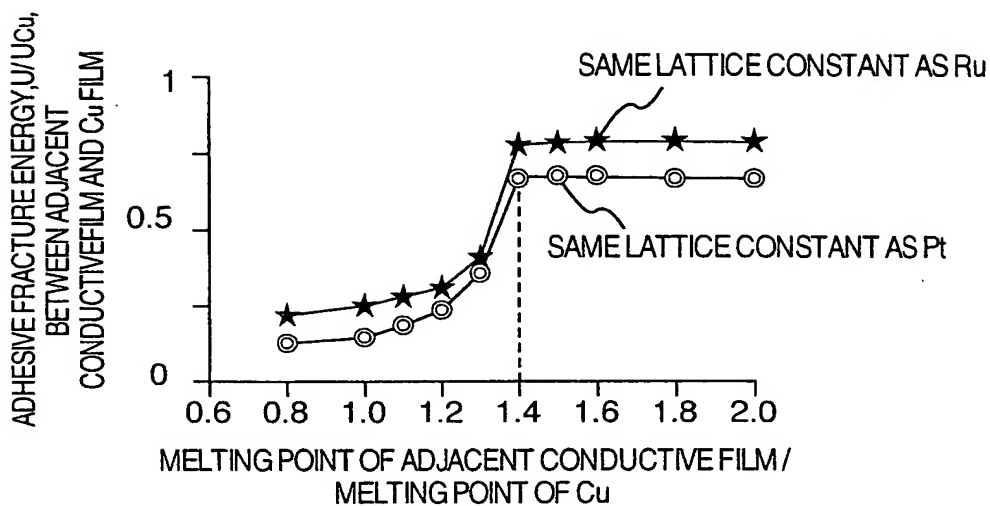
FIG.2



ATOMIC ARRANGEMENT IN CLOSEST PACKED
CRYSTAL PLANE AND LATTICE CONSTANTS a
AND b IN UNIT RECTANGULAR LATTICE

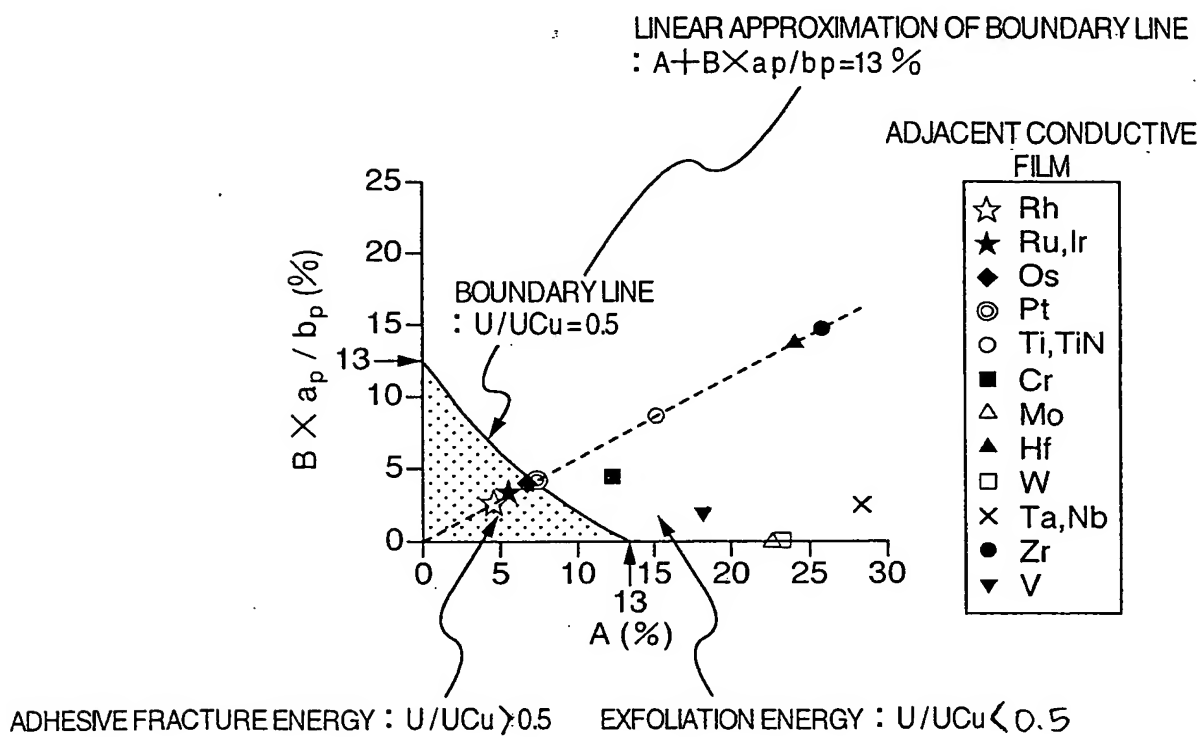
[Fig. 3]

FIG.3

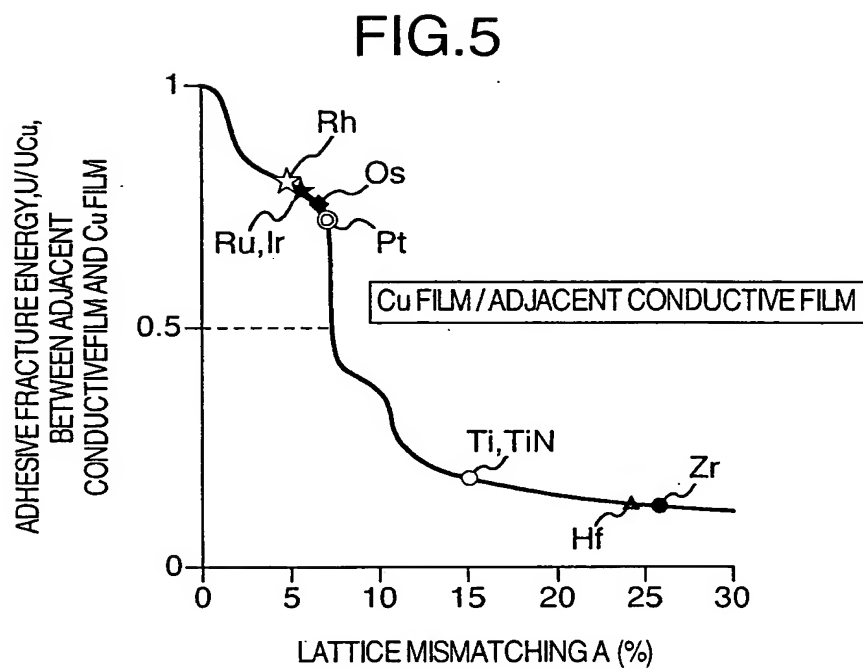


[Fig. 4]

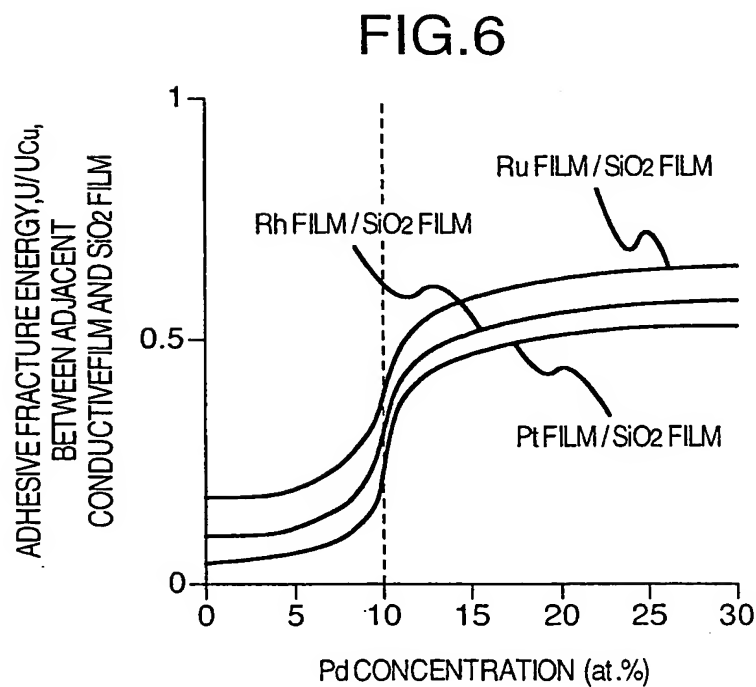
FIG.4



[Fig. 5]

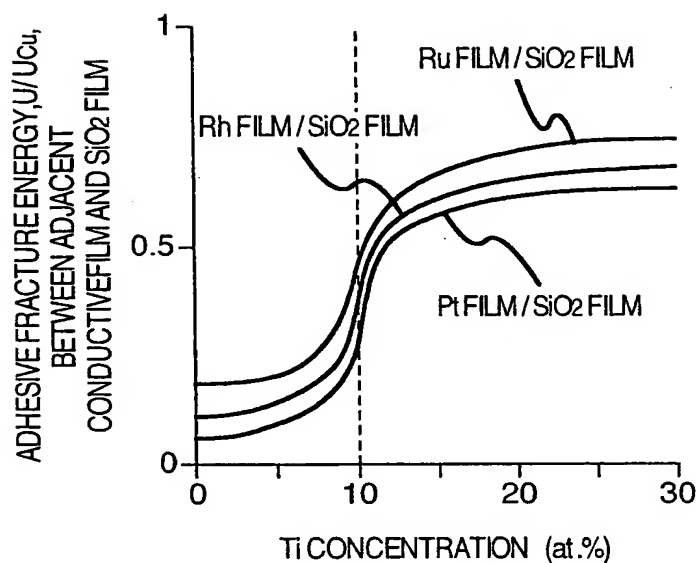


[Fig. 6]



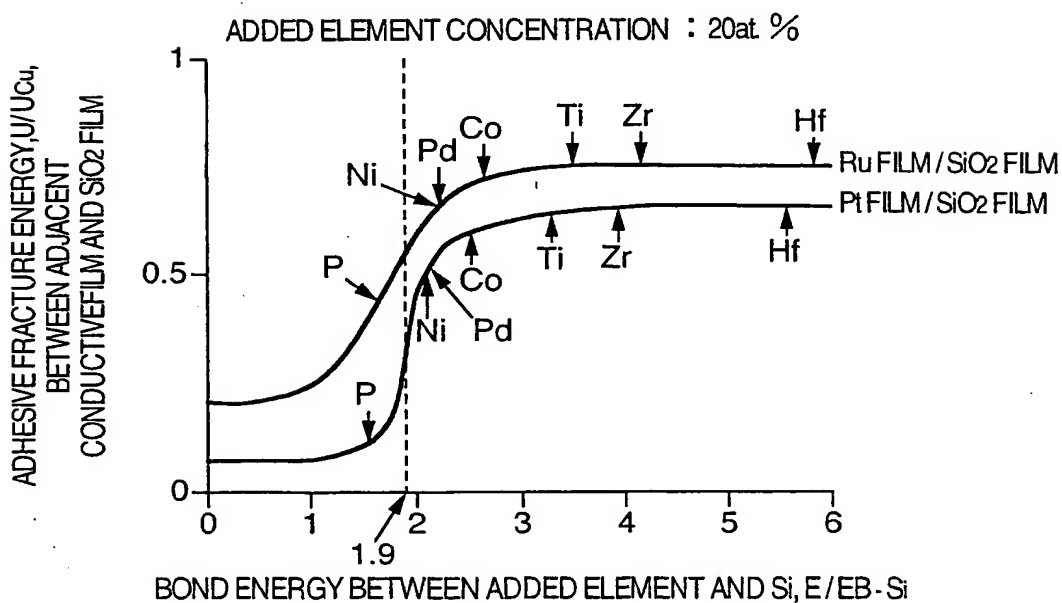
[Fig. 7]

FIG.7



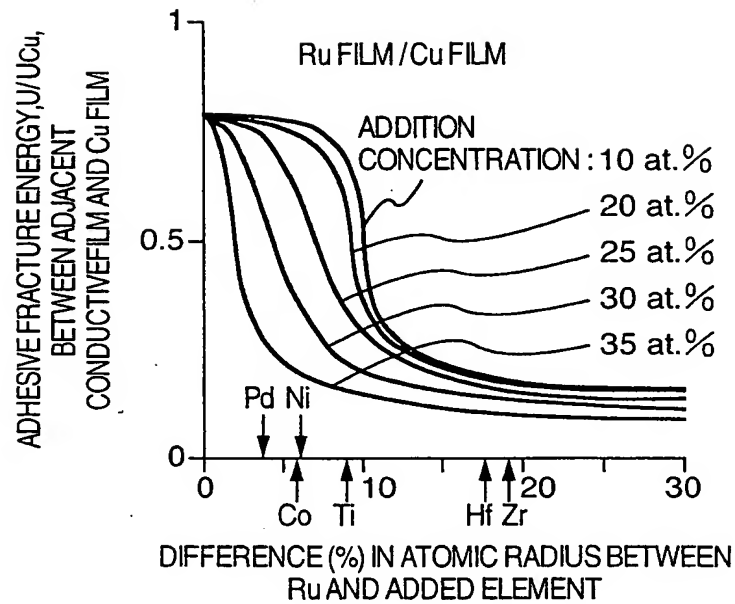
[Fig. 8]

FIG.8



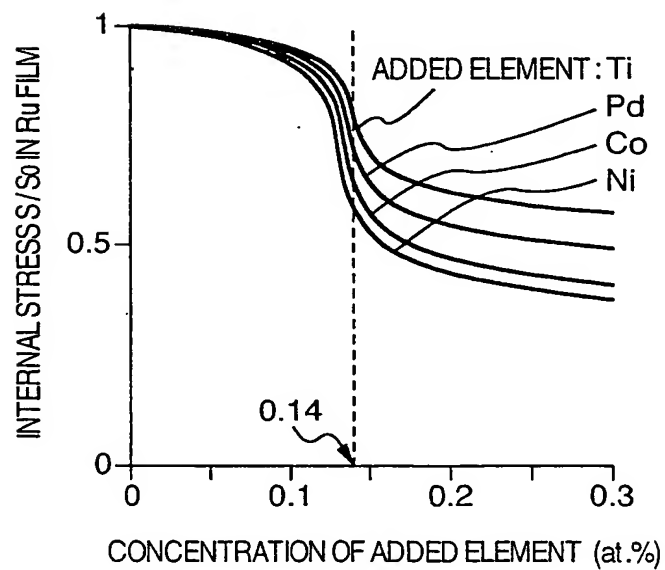
[Fig. 9]

FIG.9



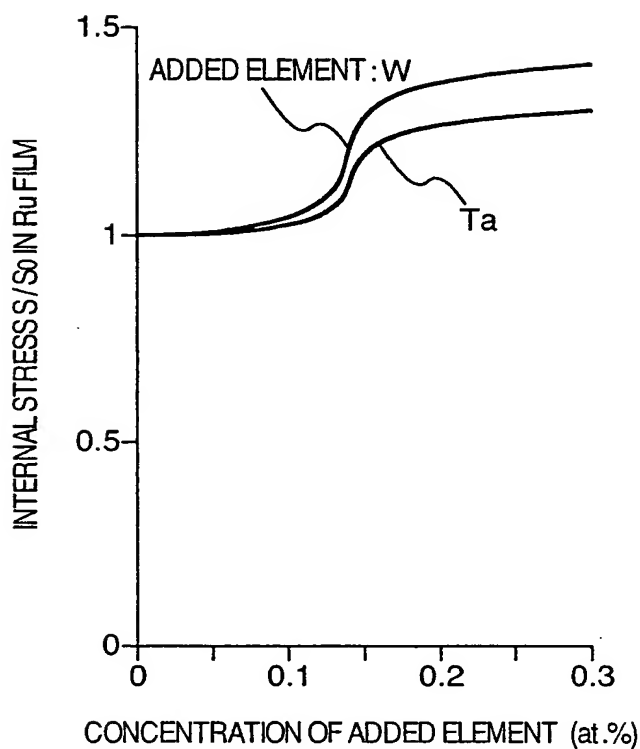
[Fig. 10]

FIG.10



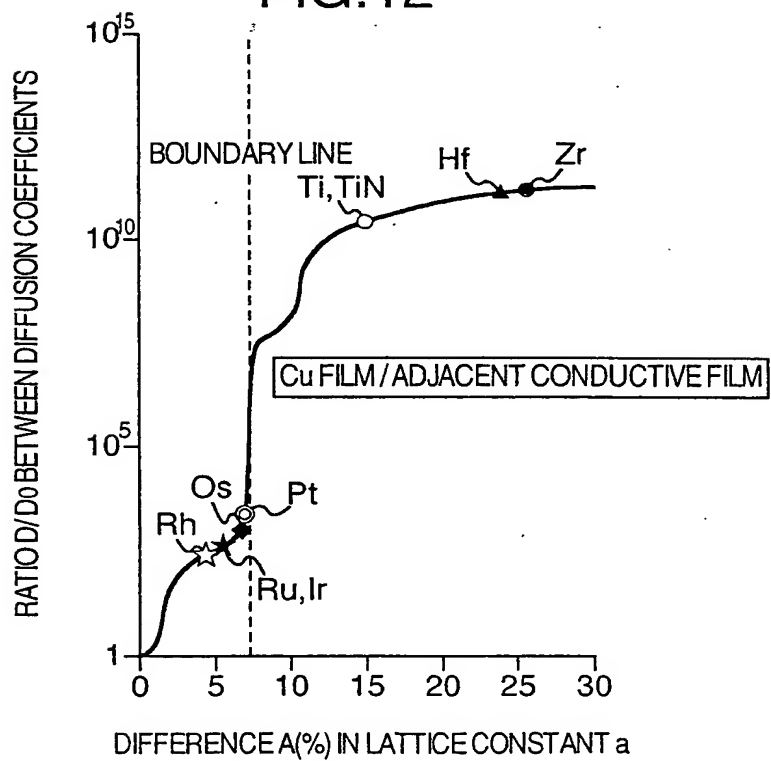
[Fig. 11]

FIG.11



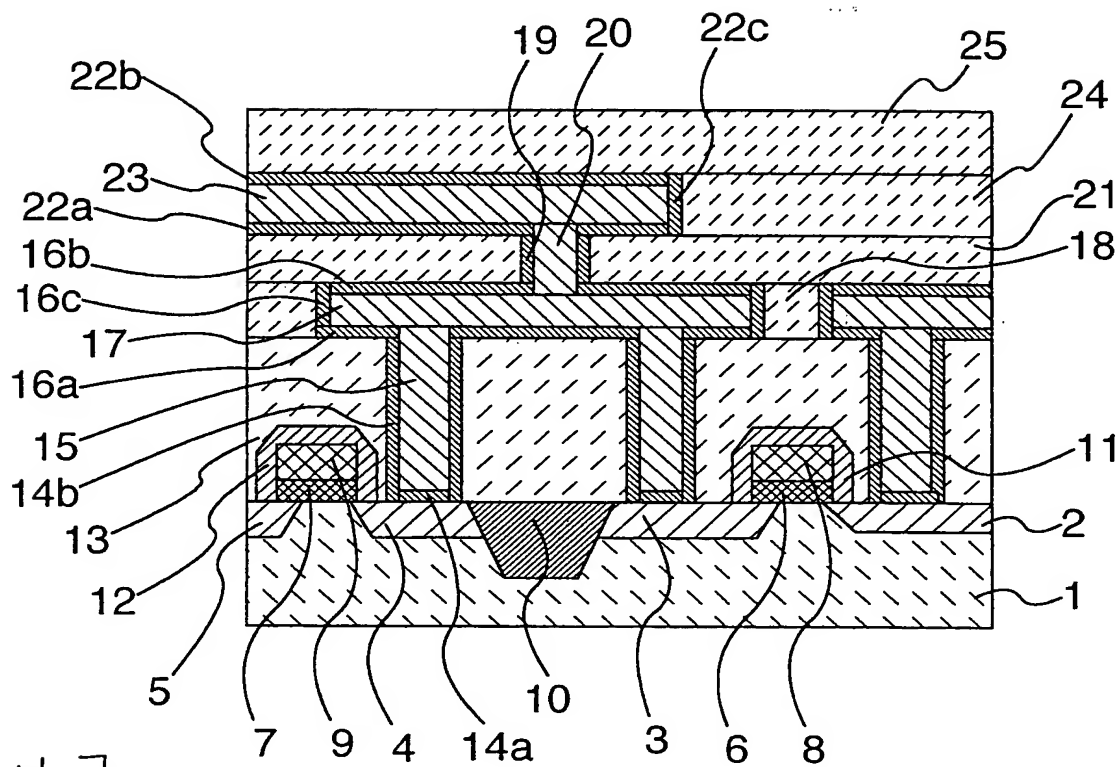
[Fig. 12]

FIG.12



[Fig. 13]

FIG.13



[Fig. 14]

FIG.14

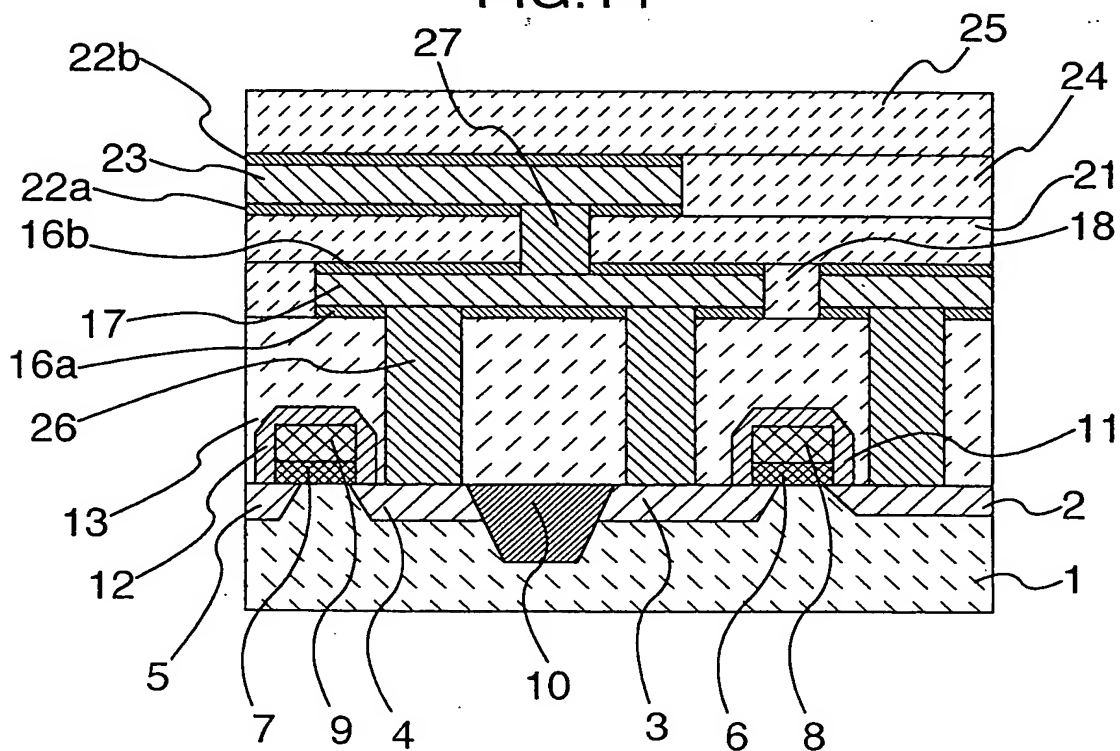
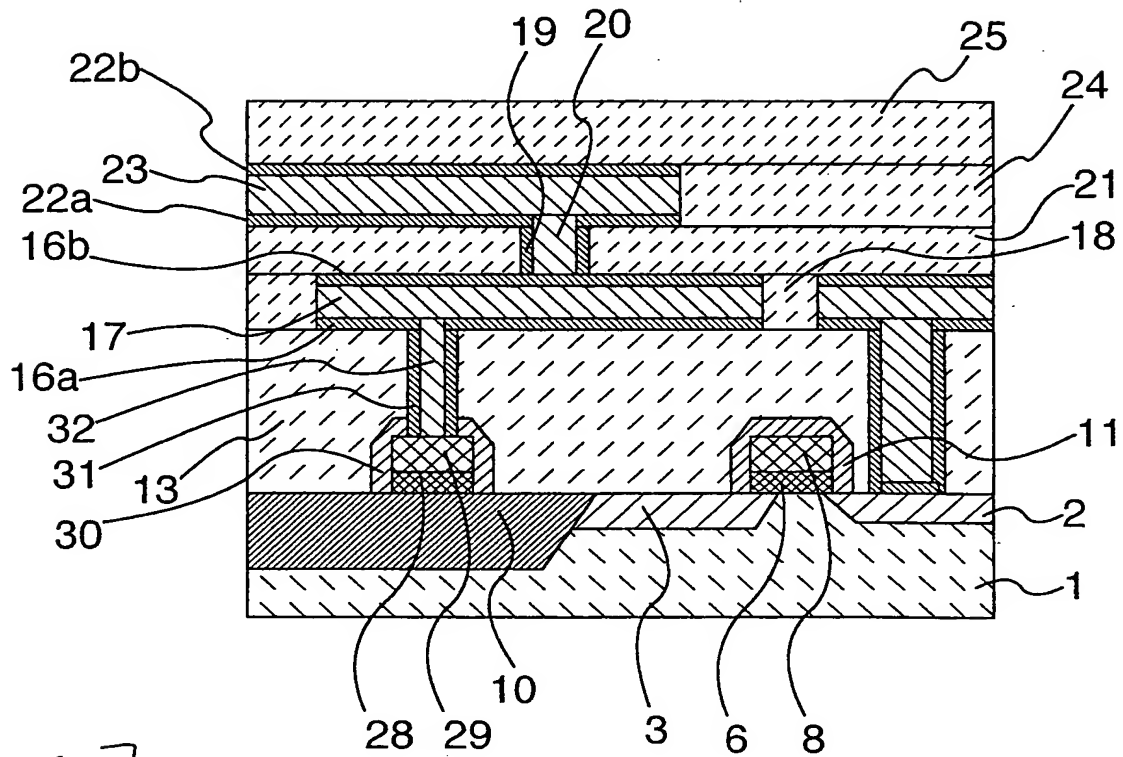
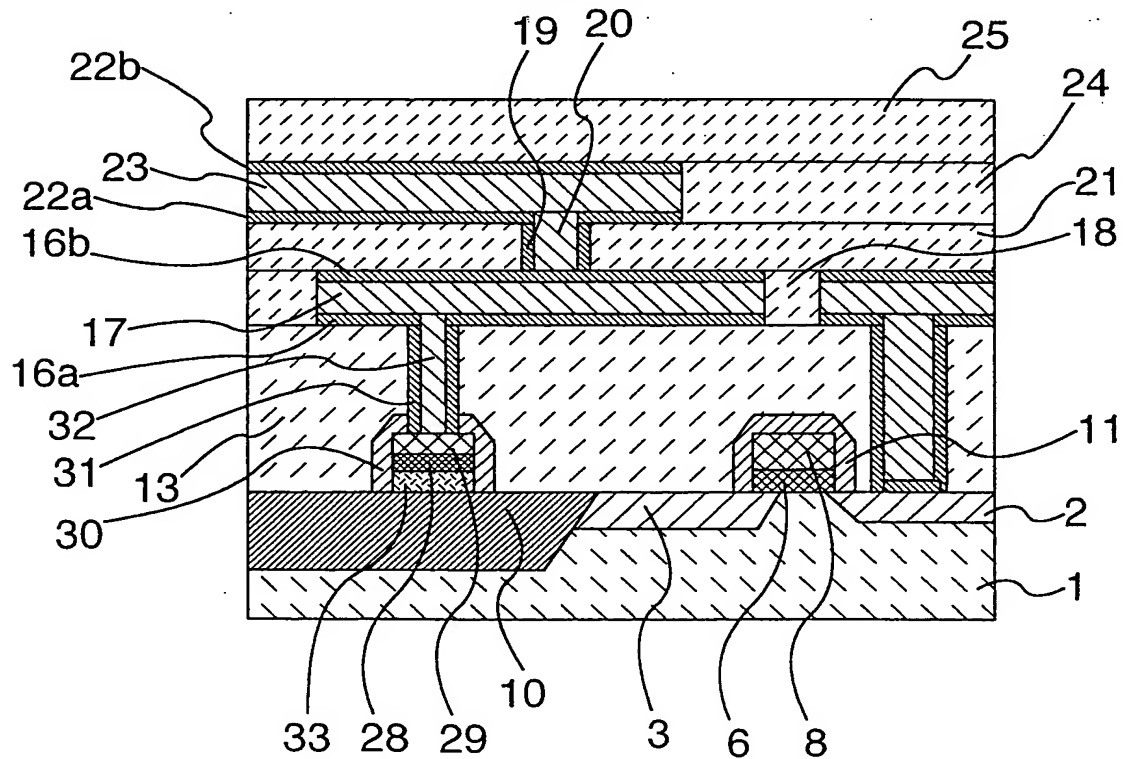


FIG.15



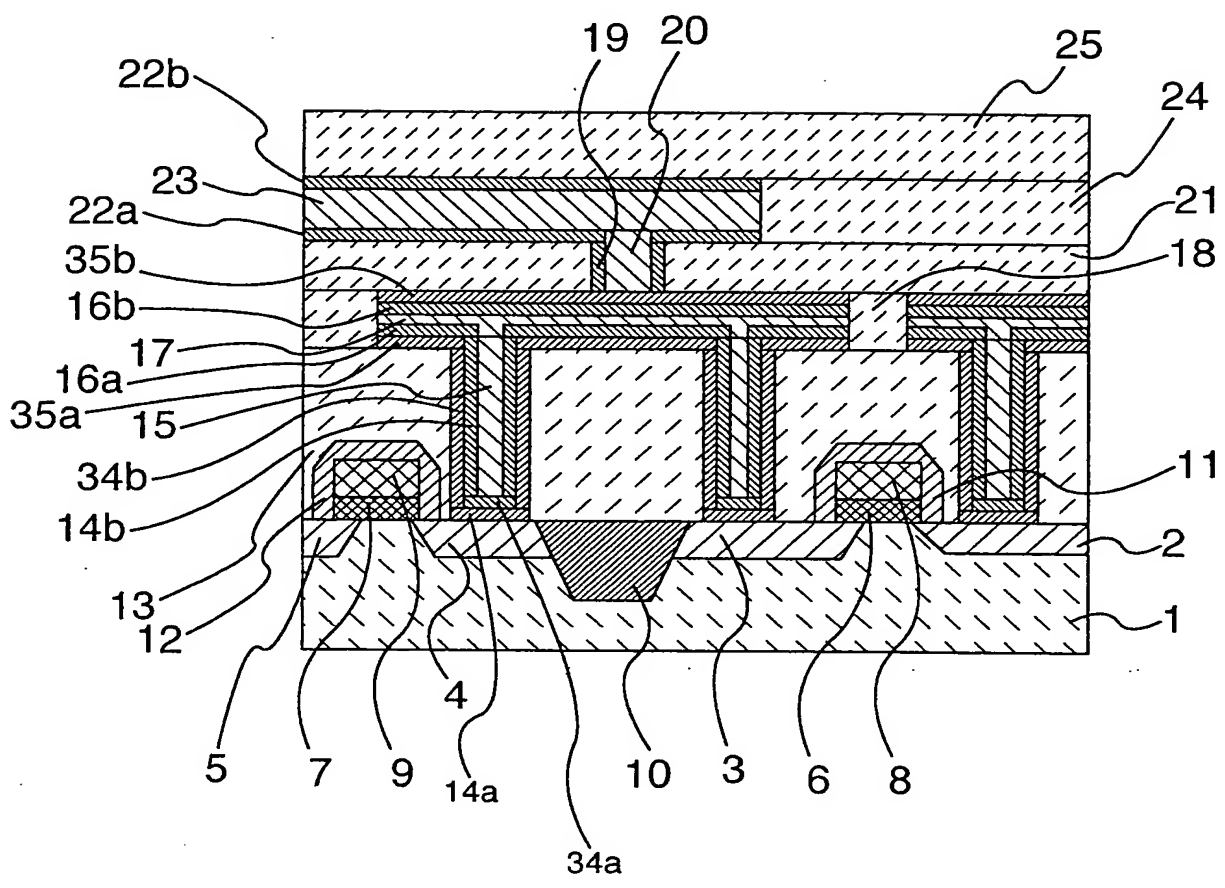
[Fig. 16]

FIG. 16



[Fig.17]

FIG.17



[Title of Document] Abstract

[Abstract]

[Problem]

In a semiconductor device having a multilayer structure comprising an insulating film, an adjacent conductive film, and a main conductive film, to provide a highly reliable semiconductor device in which defects in the multilayer structure such as adhesive fracture and cracks are difficult to occur. Further, to provide a highly reliable semiconductor device in which voids and disconnections due to migration are difficult to occur.

[Solution]

The lattice mismatching between a main constituent element of an adjacent conductive film and a main constituent element of a main conductive film is made small, the melting point of the main constituent element of the adjacent conductive film is set to be not less than 1.4 times that of the main constituent element of the main conductive film, the adjacent conductive film contains at least one different kind of element in addition to the main constituent element, the difference between the atomic radius of at least one kind of added element among the different kinds of elements and the atomic radius of the main constituent element of the adjacent conductive film is set to be not more than 10%, and the bond energy between the added element and

silicon (Si) is set to be not less than 1.9 times that of the main constituent element of the adjacent conductive film and silicon (Si).

[Selected Drawing] Fig. 1